DESIGN AND DEVELOPMENT OF A BRAINWAVE- BASED CREATIVITY AND INTELLIGENCE EVALUTATION MODEL

Synopsis
Submitted in the partial fulfilment for the requirement of
Doctor of Philosophy
In
Physics and Computer Science

Submitted by
Mr. Hardik Chadda

Under the supervision of

Prof. K. Soami Daya
Professor
Department of Physics and Computer Science
Faculty of Science
Dayalbagh Educational Institute
Agra

DEPARTMENT OF PHYSICS AND COMPUTER SCIENCE
FACULTY OF SCIENCE
DAYALBAGH EDUCATIONAL INSTITUTE (DEEMED TO BE UNIVERSITY)
DAYALBAGH, AGRA – 282005
2022

Introduction

Creativity is arguably the unique trait that humanity has. With it, we have managed to escape the present, reconstruct the past, and fantasize about the future, to visualize something that did not exist and change the world with it. And, thus, a necessary trait.

A simple google search on "Creativity" tells you that "*creativity is the use of imagination or original ideas to create something".* A fundamental skill in the modern academic curriculum[1], [2] , creativity is something way more than the abstract definition. And, defining a complex and transient phenomenon which occurs inside the brain[3] with abstraction is not the right way of comprehending the topic.

Ever since we realized the importance of creativity, we have worked for the pursuit of a more focused understanding of - What creativity is? How to measure it? And how can we develop or enhance creativity in the younger minds? These questions initiated many kinds of research starting in the first half of the 20th Century. The different approaches to the study, mostly psychological, included - cognitive approach[4], psychometric approach[5], personality development approach[6], socio-cultural approach[7], clinical approach[8], and biological approach[9]–[11]. The psychological way of understanding creativity helped in developing a correlation between creativity and divergent thinking[12], remote association[13], musical creativity[14], [15], and visual-mental imagery[16], [17]. Divergent Thinking (DT) tests that help to assess the ability of creative idea generation[12]. The Alternate Uses Task (AUT) tests are another accepted test that requires participants to novel uses for familiar objects where the number of uses generated and the uniqueness of responses is the measure of creativity[18].

The biological approach investigates the extent to which the neural and physiological mechanisms underlying creativity. These studies have been as dramatic as dissecting the brain of Albert Einstein into 240 sections and performing analysis on it[19] and have also involved non-invasive techniques to study brain activities when people are engaged in creative activities. The focus of this approach was on one of the most intricate, complex, and fascinating objects of the universe - a Brain.[20]

No matter whether you are resting or working – as you think, dream, see, and sense, your brain is always active. It never stops. It absorbs all information, compresses it, and re-wires existing data, and integrates everything into a consistent experience.

There are about 85 billion neurons in the human brain – these are the cells that carry out most of the communication in a Brain[21]. Billions of other cells carry out a range of functions to both support, nurture, and facilitate neural signaling[22].

Single neurons typically consist of a cell body and one or more axons that all end at synapses. Synapses propagate information between neurons by acting as a gateway of inhibitory or excitatory activity between the neurons. This transmission at the synapses triggers the release of neurotransmitters, which can cause a voltage change across the cell membrane and hence generates a transient and subtle electrical field, which is also called a postsynaptic potential. The postsynaptic potential of a single neuron is too tiny to be noticed.[23] However, whenever the same phenomenon occurs in a smaller group of neurons, say about 1000 or more, the resulting electrical field becomes strong.

Now, not all electrical fields generated by the brain are strong enough to spread from the tissues to the scalp surface, and hence difficult to be detected by a non-invasive measuring technique. However, the synchronized activity of pyramidal neurons in cortical brain regions can be measured from the outside on the scalp using any non-invasive Device.

An easier way of performing this task can be by placing sensors (electrodes) at the scalp surface and simply recording electrical data. This procedure is known as Electroencephalography (EEG)[24]–[26]. First applied to humans in the 1920s by German neurologist Hans Berger [27], EEG is an inexpensive, non-invasive, and a passive recording technique.

Although the firing pattern of these numerous neurons is highly complex and complicated, the electrical signals that are picked up by EEG sensors are always a mixture of several underlying base frequencies.[26], [28] Because of only a slight difference in these frequencies within a narrow band (due to individual factors, stimulus properties, or internal states), this spectrum of brain wave is subdivided based on specific frequency ranges: the delta band (1 – 4 Hz), the theta band (4 – 8 Hz), the alpha band (8 – 12 Hz), the beta band (13 – 25 Hz) and the gamma band (> 25 Hz)[24], [26], [28]. In contrast to time-frequency based EEG analysis, Event-Related Potential (ERP) analysis is performed with a focus on accessing the aspects of brief perturbations in EEG signals that occur in response to events that are defined in the experiment. The analysis of these time-series and that of ERP can help to understand the correlation of brain waves with creativity. [25], [29]–[31]

Review of Literature

In the first half of the 20th Century, there was little research on creativity because it was believed to be too frivolous and complex for scientific investigation. A pioneering exception to this was Wallas' (1926) classification of the creative process into a series of stages – preparation, incubation, illumination, and verification. [32]

Many kinds of research performed with a psychological and behavioral approach since then.

In one such study, Dean Kieth Simonton argued creativity to link with three parameters – the initial thought probability, the final utility, and the creator's prior knowledge of the utility.[33] This research linked *an element of surprise* with creativity.

Yan li, in his study, also explained the role of knowledge in creativity and creative thinking. Where too little knowledge did not give a scope to cultivate creativity, too much information indicated conventional-thinking rather than creative thinking.[33], [34]

Creativity is also said to link majorly with skills, namely, divergent thinking, remote association, musical creativity, and visual imagery.[35] The ability to create or bring something to existence is also said to be associated with a creative attitude.

According to psychologist Sternberg, personal creativity is a function of personal-intelligence, knowledge, thinking styles, personality, motivation, and environmental context. [36]

This approach towards the study of creativity led to the development of many psychology-based test models to check the levels of creativity. While some good researches performed with this context, but it lacked objectivity in the results and had abstraction in the measurement system.

The other approach to study creativity is through studying the part where it all originated, the Brain.

Many studies have involved electrophysiological methods for investigating creative cognition, making a significant stride towards the fundamental understanding of creativity.[25]

EEG-based studies

Electroencephalography (EEG) methodology in creativity research has been remarkably fruitful, establishing the potential of EEG to illuminate complex and transient creativity-related neural processes. [26], [37], [38]

The analyses of the EEG typically used methods such as Fourier Transform to create a *time-frequency* output and a power spectrum. The prominence of a band of the brain-wave is then associated with activities. The most common associations are: Delta: Deep Sleep[39], Theta: Error Monitoring, Cognitive Control[40], [41], Alpha: eye closed, relaxation, internally oriented attention network inhibition[42], Beta- being awake, affective, and cognitive processing [43] and Gamma: active processing of sensory information perpetual binding[44], [45].

Sometimes, brief perturbances were observed in the EEG signals. These disturbances may be in response to experimenter-defined events. In such instances, *Event-Related Potential (ERP)* analysis is performed. This technique involves the measurement of peaks and troughs of event-related voltage waves that are averaged across subjects[31], [37], [46], [47].The ERP components, which are the wave-data at a specific moment, are of interest in the analysis. The commonly accessed ERP components are P50 - sensory gating; N200 - oddball effect; N2pc - visual attention selection, P3a - task-related attention; P3b - attention, and memory; and N400 - semantic congruity.[48], [49]

The Alpha Power

The recent advances in the field and the empirical work on creativity as divergent thinking, remote associations, and visual imagery, are mentioned below. The alpha-band activity is associated with better performance in *Divergent Thinking* (DT) tasks[50], [51]. Even during *Alternate Uses Tasks* (AUTs), a higher alpha-power was observed in frontal and parietal regions. During similar tasks-based tests, a higher power of alpha-band was observed during the phase of idea generation and then again just before responding. Subjects who performed better in DT tests were seen to have sustained alpha power in frontal and parietal regions for longer durations.[52], [53] Good performers of the DT test were also reported to be good at consistently inhibiting the interfering external stimuli so that creative ideas could be generated. Thereby, a decrease in alpha power was observed during DT tests that involved visual processing and hence a strong externally oriented attention[54]. Since there was a strong correlation seen between internally-oriented attention and alpha power, closing eyes resulted in better DT performance[55].

Creativity was also seen in the ability to connect relatively distant ideas and creating novel associations. *Compound Remote Association* (CRA)[56] tasks examined this ability by giving unrelated

words and finding a word that is common to all. During CRA tests, alpha power was found to increase in the right parietal zone when the subjects used their insight to come up with the answer[57]. The parietal lobe is known to show sensory integrations [58]. Increased alpha power in this zone could thereby be interpreted as suppression of sensory information to gain internally-oriented attention for the requirement of the task requiring an insight[59].

An increase in alpha power is also reported in the occipital cortex.

Visual Mental Imagery can also be a parameter to measure creativity as it involves an experience of sensory information without an actual direct external stimulus. Such processes rely majorly on the visual cortex. In tasks that demand higher visual processing, such as Picture Completion Tasks, alpha power was found below the baseline in parietal and occipital regions and higher in subjects tending to have a lower creativity level[17], [60]. It was noteworthy that during this test, there was an increase in alpha level when the subject tried to mentally elaborate on their drawing.

The Theta Power

Along with an increase in alpha power, a decrease in theta power has also been reported in the experiments. In one of the experiments, involving sorting unusual scenes on a computer scene, a decrease in theta power in the mid-frontal region is associated with high scores of creativities. [41], [61]

The Gamma Power

During CRA tests, right after the alpha-band activity, a burst of gamma-band was seen to be originating from the right temporal lobe. Gamma is known to have an association with memory and sensory processes. It may, thus, have involvement in insight-based creativity tasks as it helps in making of perception from the given information. [62], [63]

Other reports have mentioned a reduction in gamma-band over the central region in subjects tending to have higher creativity levels from the perspective of tests involving internally-oriented attention requirement. [64], [65]

Fewer researches have mentioned the role of gamma-band synchronization in the measurement of creativity levels, leaving a room open for more research in the area.

EEG band-power during technology-involving tasks.

Coding requires significantly high cognitive skills and information processing ability. Programming education has become increasingly popular and is believed to boost the child's creativity. In an experiment involving 36 programmers (18 novice and 18 experts), subjects were asked to study a Java code, choose a relevant answer from the choice of four, close their eyes for 30 seconds, open the eyes as the reminder bell rings, and continue the process. Brain waves were recorded throughout the process. The results showed a high beta and gamma power, along with a significant difference in beta power between expert and novice programmers, especially in the F3 electrode. Additionally, during programming comprehension, the P8 electrode also showed a significantly higher beta and gamma power of experts than that of the novice group.[66]

Another experiment involved a group of 20 students playing Pictionary, and while they were at it and their inputs and EEG data were recorded. The experiment showed high-frequency oscillations in the Frontal and Central regions while subjects were describing the word, associating to high cognition levels, and Low-Frequency Oscillations in the Parietal and Occipital Regions when drawing; associating with visual processing along with sensory-motor integration. The experiment concluded on how drawing can be associate with visual imagery and hence the creativity. [67]

There are other EEG-based studies as well that have demonstrated how certain activities can mimic a similar band-power as it happens during creativity tests. However, no significant research was found if using such activities for training children at an early age can take advantage of the neuroplasticity of a brain and make them more creative. Such a study can be very fruitful in the formulation of an Education Policy that helps to cultivate children as innovators and creative thinkers.

Gardner's theory of multiple intelligence.

This study will also incorporate a relatively new approach to intelligence – the theory of multiple intelligence – proposed by Harvard psychologist Howard Gardner. He, in his book, proposed that there are eight intelligences along with a possibility of the ninth one – "existential intelligence."

These intelligences are as follows: (1) Visual-Spatial Intelligence, (2) Linguistic-verbal Intelligence, (3) Logical-Mathematical Intelligence, (4) Bodily-Kinesthetic Intelligence, (5) Musical Intelligence, (6) Interpersonal Intelligence, (7) Intrapersonal Intelligence, and (8) Naturalistic Intelligence.

While some criticized these intelligences as mere talents or abilities, many educators have incorporated 'multiple intelligence' in their teaching philosophies and is enjoyed among the educator's community.

Conceptual Framework of the Study

The conceptual framework of the study is given below:

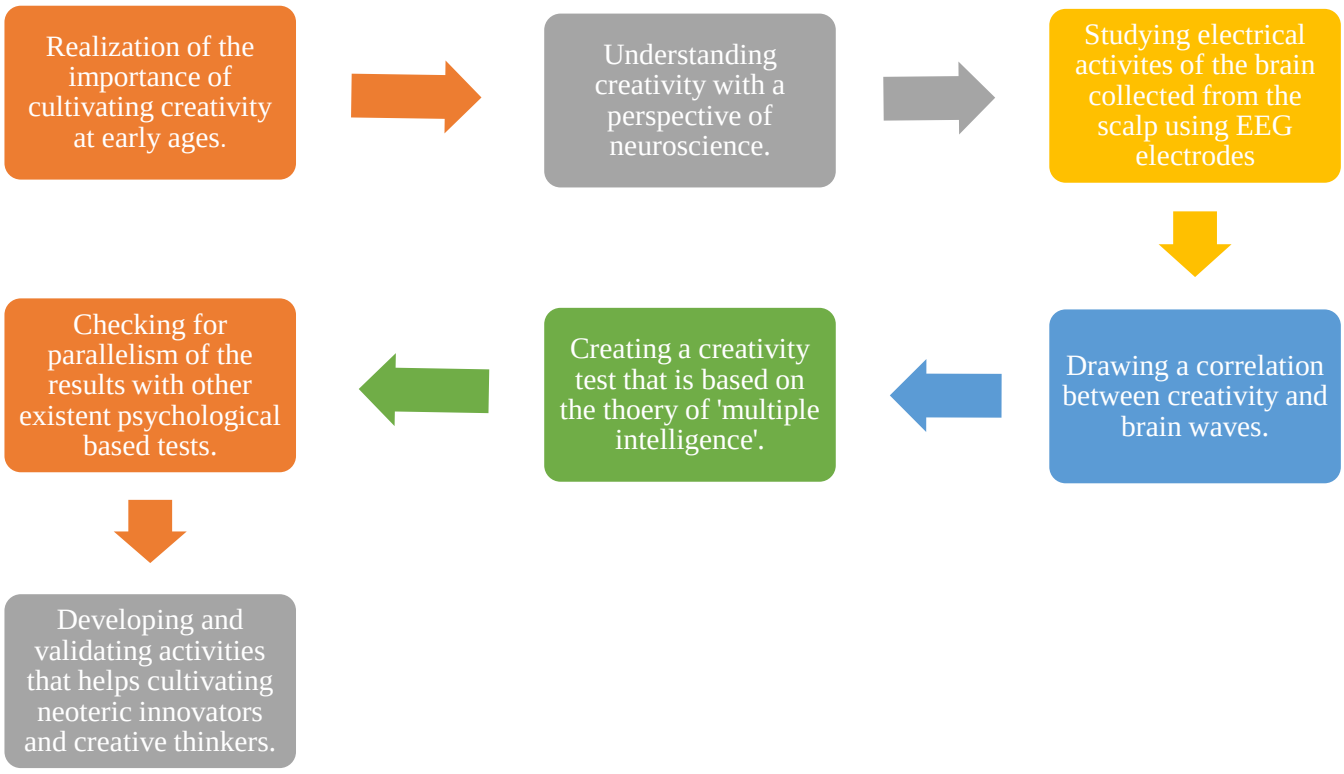
Realization of the importance of cultivating creativity at early ages.
Understanding creativity with a perspective of neuroscience.
Studying electrical activites of the brain collected from the scalp using EEG electrodes
Drawing a correlation between creativity and brain waves.
Creating a creativity test that is based on the thoery of 'multiple intelligence'.
Checking for parallelism of the results with other existent psychological based tests.
Developing and validating activities that helps cultivating neoteric innovators and creative thinkers.

Fig 1: Conceptual framework of the study

Objective of the Study

The main goal of the proposed study is to design a brain-based evaluation model for children that is independent of any bias and gives a better picture of the child's brain development over a period.

The objectives of the study are:

i. To study the correlation between brain waves and creativity.

ii. To develop a model of evaluation based on brain-wave activities.

iii. To create a parallelism between the existent standardized tests for creativity and the evaluation model developed in the scope of this study.

iv. To develop standard activities, each stimulating the brain differently, while which the EEG signals will be acquired.

Hypothesis of the Study

It is hypothesized that *creative thinking* is linked with *Creativity* that happens inside the brain and thus if we look closer to source of action (the brain) rather than the actions itself, opposite of what happens in the current standardized tests, we will be able to see growth in a better way. This will also help in the development of an evaluation system independent of bias of any sort and give room to for students who do not perform well in the standardized testing that happens in schools and hence make *inclusive education* possible.

Research Methodology

To achieve the above-mentioned objectives following methodologies will be incorporated:

i. Brain responses will be studied by reading the electrical signals generated by the brain from different location on the scalp.

   For this purpose, a cap can be developed for children, rigged with 14 EEG sensors at specific locations, so that they pick up the activities from the location on the scalp as depicted in the image below:

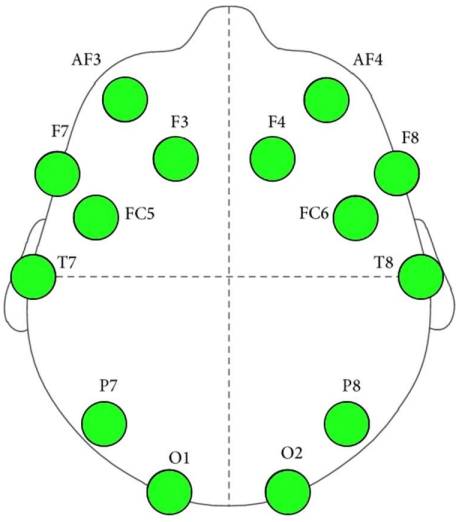

Fig 2: Position of the electrodes on the scalp. (Fc= fronto-central, F= frontal, C=central, P= Parietal; O=occipital; T=Temporal, Af=auxiliary-frontal; z=zero)

In the 10-20 system of electrode placement, electrodes name begin with a letter which indicates the name of the lobe where the electrode is placed. Each electrode name ends with a number or

letter which indicates the distance from the midline, which is odd for left hemisphere and even for the right hemisphere. The electrodes on the midline has a suffix – 'z' for zero.

ii. A group of 20 students from middle school will be selected according to the following criteria, for the purpose of conducting the experiment:

Table 1: Children Selection Criteria for the Experiment

Criteria	No. of students	
	Male	Female
Students with high scores in the standardized school tests	2	2
Students with low scores in the standardized school tests	2	2
Students with improper formal education	2	2
Students good at drawing and/or crafting	1	1
Students good at singing	1	1
Students good at playing musical instrument	1	1
Students good at dancing	1	1
Total	10	10
Grand Total		20

EEG Signals picked up from the electrodes at different locations will be recorded for children while they perform creativity tasks (DT and AUT) that triggers brain activities of different lobes of the brain. These activities will be of the children will be recorded using a high definition camera for a signal-anomaly check.

The collected signals may make artifacts and will be corrected manually with a feedback from the camera. The artifacts can be because of movements or an external stimulus catching subject's attention.

A study will be performed over it. The study will involve frequency-power analysis of the temporal signal giving information of the different waves recorded over a period.

The study can be extended by involving stimulus-relevant Event-Related Potentials (ERPs) where negative and positive peaks for difference wave will be noted and correlated with the brain-wave response for the external stimuli.

iii. The results from the experiment will help in formulating a fundamental understanding of the correlation between brain activity and the given stimuli (activities that trigger divergent and creative thinking).

This understanding will further help in developing a model that will make a direct relationship between creativity and brain waves. Once it is done, the correlation derived can be used to train a machine learning model that can be able to detect if the incoming EEG signals are corresponding to creative thinking or not. The model can also be trained to score the creativity level using Principal Component Analysis (PCA).

iv. A parallelism with common creativity tests will be performed with these tests and results for our model will be validated.

v. A training programme of the students will be organized which would include technology-oriented skills – Python programming, Practical electronics and Gadget Making, Computer-Aided Designing. The training will make an extensive use of D.I.Y. kits that will also be designed in the scope of this study. The training will continue for a period of at least six months during which EEG scan will be performed on the children monthly. Trends in the EEG band power will be analyzed over the training period and hence the role of these activities in creativity training will be studies.

References

[1] D. Wyse and A. Ferrari, "Creativity and education: Comparing the national curricula of the states of the European Union and the United Kingdom," Br. Educ. Res. J., vol. 41, no. 1, pp. 30–47, 2015, doi: 10.1002/berj.3135.

[2] D. Trotman, "Creativity in the primary classroom," Educ. 3-13, 2014, doi: 10.1080/03004279.2013.777085.

[3] K. M. Heilman, Creativity and the brain. 2005.

[4] M. A. Runco and I. Chand, "Cognition and creativity," Educ. Psychol. Rev., 1995, doi: 10.1007/BF02213373.

[5] A. K. Sinha and C. Singh, "Measurement of scientific creativity," Indian J. Psychom. Educ., 1987.

[6] M. Batey and A. Furnham, “Creativity, intelligence, and personality: A critical review of the scattered literature,” Genet. Soc. Gen. Psychol. Monogr., 2006, doi: 10.3200/MONO.132.4.355-430.

[7] H. Tekin and O. F. Tekdogan, “Socio-Cultural Dimension of Innovation,” Procedia - Soc. Behav. Sci., 2015, doi: 10.1016/j.sbspro.2015.06.438.

[8] G. Murray and S. L. Johnson, “The clinical significance of creativity in bipolar disorder,” Clinical Psychology Review. 2010, doi: 10.1016/j.cpr.2010.05.006.

[9] O. Vartanian, A. S. Bristol, and J. C. Kaufman, Neuroscience of creativity. 2013.

[10] B. Onarheim and M. Friis-Olivarius, “Applying the neuroscience of creativity to creativity training,” Front. Hum. Neurosci., 2013, doi: 10.3389/fnhum.2013.00656.

[11] D. W. Zaidel, “Creativity, brain, and art: Biological and neurological considerations,” Frontiers in Human Neuroscience. 2014, doi: 10.3389/fnhum.2014.00389.

[12] M. A. Runco and S. Acar, “Divergent Thinking as an Indicator of Creative Potential,” Creativity Research Journal. 2012, doi: 10.1080/10400419.2012.652929.

[13] C. Rominger, A. Fink, E. M. Weiss, J. Bosch, and I. Papousek, “Allusive thinking (remote associations) and auditory top-down inhibition skills differentially predict creativity and positive schizotypy,” Cogn. Neuropsychiatry, 2017, doi: 10.1080/13546805.2016.1278361.

[14] L. A. Dikaya and I. A. Skirtach, “Neurophysiological correlates of musical creativity: The example of improvisation,” Psychol. Russ. State Art, 2015, doi: 10.11621/pir.2015.0307.

[15] M. López-González and C. J. Limb, “Musical creativity and the brain.,” Cerebrum, 2012.

[16] T. Helstrup, Imagery, Creativity, and Discovery - A Cognitive Perspective. 1993.

[17] L. M. Pidgeon et al., “Functional neuroimaging of visual creativity: a systematic review and meta-analysis,” Brain Behav., 2016, doi: 10.1002/brb3.540.

[18] C. Martindale and A. Dailey, “Creativity, primary process cognition and personality,” Pers. Individ. Dif., 1996, doi: 10.1016/0191-8869(95)00202-2.

[19] D. Falk, F. E. Lepore, and A. Noe, “The cerebral cortex of Albert Einstein: A description and preliminary analysis of unpublished photographs,” Brain, 2013, doi: 10.1093/brain/aws295.

[20] M. E. Raichle and M. A. Mintun, “Brain work and brain imaging,” Annual Review of

Neuroscience. 2006, doi: 10.1146/annurev.neuro.29.051605.112819.

[21] D. M. Lovinger, “Communication networks in the brain: Neurons, receptors, neurotransmitters, and alcohol,” Alcohol Research and Health. 2008.

[22] G. Perea and A. Araque, “GLIA modulates synaptic transmission,” Brain Research Reviews. 2010, doi: 10.1016/j.brainresrev.2009.10.005.

[23] A. Hasenstaub, Y. Shu, B. Haider, U. Kraushaar, A. Duque, and D. A. McCormick, “Inhibitory postsynaptic potentials carry synchronized frequency information in active cortical networks,” Neuron, 2005, doi: 10.1016/j.neuron.2005.06.016.

[24] M. Teplan, “Fundamentals of EEG measurement,” Meas. Sci. Rev., 2002.

[25] A. Dietrich and R. Kanso, “A review of EEG, ERP, and neuroimaging studies of creativity and insight,” Psychol. Bull., 2010, doi: 10.1037/a0019749.

[26] P. Olejniczak, “Neurophysiologic basis of EEG,” 2006, doi: 10.1097/01.wnp.0000220079.61973.6c.

[27] R. Jung and W. Berger, “[Fiftieth anniversary of Hans Berger’s publication of the electroencephalogram. His first records in 1924--1931 (author’s transl)].,” Arch. Psychiatr. Nervenkr., 1979, doi: 10.1007/BF00344814.

[28] Brainworks, “What Are Brainwaves?,” Brainworks, 2007.

[29] A. P. F. Key, G. O. Dove, and M. J. Maguire, “Linking brainwaves to the brain: An ERP primer,” Developmental Neuropsychology. 2005, doi: 10.1207/s15326942dn2702_1.

[30] M. L. Smith, T. F. Collura, and J. Tarrant, “Neurofeedback,” in EEG/ERP Analysis: Methods and Applications, 2014.

[31] M. M. Murray, D. Brunet, and C. M. Michel, “Topographic ERP analyses: A step-by-step tutorial review,” Brain Topography. 2008, doi: 10.1007/s10548-008-0054-5.

[32] E. Sadler-Smith, “Wallas’ Four-Stage Model of the Creative Process: More Than Meets the Eye?,” Creat. Res. J., 2015, doi: 10.1080/10400419.2015.1087277.

[33] D. K. Simonton, “Defining Creativity: Don’t We Also Need to Define What Is Not Creative?,” J. Creat. Behav., 2018, doi: 10.1002/jocb.137.

[34] R. W. Weisberg, “Creativity and Knowledge: A Challenge to Theories,” in Handbook of

Creativity, 2014.

[35] C. E. Stevens and D. L. Zabelina, “Creativity comes in waves: an EEG-focused exploration of the creative brain,” Current Opinion in Behavioral Sciences. 2019, doi: 10.1016/j.cobeha.2019.02.003.

[36] E. L. Grigorenko and R. J. Sternberg, “Thinking Styles,” in International Handbook of Personality and Intelligence, 1995.

[37] R. Sharp, N. R. Swerdlow, and D. L. Braff, EEG and ERPs. 2011.

[38] L. J. Hirsch and R. P. Brenner, “EEG Basics,” in Atlas of EEG in Critical Care, 2010.

[39] G. G. Knyazev, “EEG delta oscillations as a correlate of basic homeostatic and motivational processes,” Neuroscience and Biobehavioral Reviews. 2012, doi: 10.1016/j.neubiorev.2011.10.002.

[40] P. Luu, D. M. Tucker, and S. Makeig, “Frontal midline theta and the error-related negativity: Neurophysiological mechanisms of action regulation,” Clin. Neurophysiol., 2004, doi: 10.1016/j.clinph.2004.03.031.

[41] J. F. Cavanagh and M. J. Frank, “Frontal theta as a mechanism for cognitive control,” Trends in Cognitive Sciences. 2014, doi: 10.1016/j.tics.2014.04.012.

[42] N. R. Cooper, R. J. Croft, S. J. J. Dominey, A. P. Burgess, and J. H. Gruzelier, “Paradox lost? Exploring the role of alpha oscillations during externally vs. internally directed attention and the implications for idling and inhibition hypotheses,” Int. J. Psychophysiol., 2003, doi: 10.1016/S0167-8760(02)00107-1.

[43] L. Berk, C. Alphonso, N. Thakker, and B. Nelson, “Humor similar to meditation enhances EEG power spectral density of gamma wave band activity (31-40Hz) and synchrony (684.5),” FASEB J., 2014.

[44] T. R. Schneider, S. Debener, R. Oostenveld, and A. K. Engel, “Enhanced EEG gamma-band activity reflects multisensory semantic matching in visual-to-auditory object priming,” Neuroimage, 2008, doi: 10.1016/j.neuroimage.2008.05.033.

[45] W. H. R. Miltner, C. Braun, M. Arnold, H. Witte, and E. Taub, “Coherence of gamma-band EEG activity as a basis for associative learning,” Nature, 1999, doi: 10.1038/17126.

[46] R. Gu, “ERP Experimental design,” in EEG Signal Processing and Feature Extraction, 2019.

[47] S. Makeig and J. Onton, “ERP Features and EEG Dynamics: An ICA Perspective,” in The Oxford Handbook of Event-Related Potential Components, 2012.

[48] S. A. Kotz, B. Opitz, and A. D. Friederici, “ERP effects of meaningful and non-meaningful sound processing in anterior temporal patients,” Restor. Neurol. Neurosci., 2007.

[49] M. Cecchi et al., “P2-080: Neuropsychological correlates of erp cognitive measures in Alzheimer’s disease,” Alzheimer’s Dement., 2015, doi: 10.1016/j.jalz.2015.06.617.

[50] M. Benedek, “The neuroscience of creative idea generation,” in Exploring Transdisciplinarity in Art and Sciences, 2018.

[51] A. Fink and M. Benedek, “EEG alpha power and creative ideation,” Neuroscience and Biobehavioral Reviews. 2014, doi: 10.1016/j.neubiorev.2012.12.002.

[52] D. Schwab, M. Benedek, I. Papousek, E. M. Weiss, and A. Fink, “The time-course of EEG alpha power changes in creative ideation,” Front. Hum. Neurosci., 2014, doi: 10.3389/fnhum.2014.00310.

[53] A. Camarda et al., “Neural basis of functional fixedness during creative idea generation: An EEG study,” Neuropsychologia, 2018, doi: 10.1016/j.neuropsychologia.2018.03.009.

[54] M. Benedek, S. Bergner, T. Könen, A. Fink, and A. C. Neubauer, “EEG alpha synchronization is related to top-down processing in convergent and divergent thinking,” Neuropsychologia, 2011, doi: 10.1016/j.neuropsychologia.2011.09.004.

[55] S. M. Ritter, J. Abbing, and H. T. van Schie, “Eye-Closure Enhances Creative Performance on Divergent and Convergent Creativity Tasks,” Front. Psychol., 2018, doi: 10.3389/fpsyg.2018.01315.

[56] E. M. Bowden and M. Jung-Beeman, “Normative data for 144 compound remote associate problems,” Behavior Research Methods, Instruments, and Computers. 2003, doi: 10.3758/BF03195543.

[57] K. Rothmaler, R. Nigbur, and G. Ivanova, “New insights into insight: Neurophysiological correlates of the difference between the intrinsic ‘aha’ and the extrinsic ‘oh yes’ moment,” Neuropsychologia, 2017, doi: 10.1016/j.neuropsychologia.2016.12.017.

[58] T. Gebuis, W. Gevers, and R. Cohen Kadosh, “Topographic representation of high-level cognition: Numerosity or sensory processing?,” Trends in Cognitive Sciences. 2014, doi: 10.1016/j.tics.2013.10.002.

[59] M. Jung-Beeman et al., “Neural activity when people solve verbal problems with insight,” PLoS Biol., 2004, doi: 10.1371/journal.pbio.0020097.

[60] N. E. Sviderskaya, G. V. Taratynova, and R. G. Kozhedub, “The effects of the experience of forming visual images on the spatial organization of the EEG,” Neurosci. Behav. Physiol., 2006, doi: 10.1007/s11055-006-0130-9.

[61] W. Klimesch, “EEG alpha and theta oscillations reflect cognitive and memory performance: A review and analysis,” Brain Research Reviews. 1999, doi: 10.1016/S0165-0173(98)00056-3.

[62] C. S. Herrmann, M. H. J. Munk, and A. K. Engel, “Cognitive functions of gamma-band activity: Memory match and utilization,” Trends Cogn. Sci., 2004, doi: 10.1016/j.tics.2004.06.006.

[63] E. Başar, C. Başar-Eroglu, S. Karakaş, and M. Schürmann, “Gamma, alpha, delta, and theta oscillations govern cognitive processes,” Int. J. Psychophysiol., 2001, doi: 10.1016/S0167-8760(00)00145-8.

[64] A. Berkovich-Ohana, J. Glicksohn, and A. Goldstein, “Mindfulness-induced changes in gamma band activity - Implications for the default mode network, self-reference and attention,” Clin. Neurophysiol., 2012, doi: 10.1016/j.clinph.2011.07.048.

[65] R. J. Barry, A. R. Clarke, M. Hajos, R. McCarthy, M. Selikowitz, and F. E. Dupuy, “Resting-state EEG gamma activity in children with Attention-Deficit/Hyperactivity Disorder,” Clin. Neurophysiol., 2010, doi: 10.1016/j.clinph.2010.04.022.

[66] S. Lee et al., “Comparing Programming Language Comprehension between Novice and Expert Programmers Using EEG Analysis,” 2016, doi: 10.1109/BIBE.2016.30.

[67] R. van der Weel and A. Van der Meer, “Only Three Fingers Write, But The Whole Brain Works: Is the pen mightier than the word?,” 2017, doi: 10.5176/2251-1865_cbp17.1.